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Whole body countings and its applications in bio-medical sciences

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Abstract: A whole body counter detects a fraction of the gamma radiation emitted rom the radionuclides in the human body. From the observed counting rate and suitable calibration procedures, the amount of activity within the subject can be calculated. In this communication, the early development and the requirements of a multipurpose whole body counter are described. Constructional details and special features of such system installed at the Institute of Nuclear Medicine and Allied Sciences (INMAS) are outlined. The various physical and bio-medical investigations carried out at the Institute are described. The results of total body potassium measurements and iron and Vitamin B_{12} absorption studied are discussed. The other potential bio-medical uses of the system are described.

Keywords: Whole body counters, bio-medical research, applications.

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1. Introduction

Whole Body Counters are the instruments which measure low level of radioactivity within the human body. The first generation of whole body counters were built in the mid of 1930's to assess accidental internal contamination for example ingestion of ^{226}Ra from luminous paints. The discovery of nuclear fission and subsequent interest in nuclear reactors and weapons provided impetus for the construction of a new generation of monitors. As a result of the present day ready availability of large number of radioactive isotopes and labelled biological compounds, the main interest in the whole body monitors has shifted from their initial use in radiological protection to the field of clinical and bio-medical research. In fact, around 75% of the existing whole body counters of the world are being used wholly or partially for clinical work with administered radiotracers.

2. Design criteria and design of a whole body counter

The three main determinants of whole body monitor design and type, are the nature of the radiation detector, the subject detector geometry and the protection provided to shield the counting system from radiation sources external to it. Ideally, a whole body counter should be able to detect, identify and measure

minute quantity of radioactivity and its response should depend only on the quantity and not on the distribution of the radioactivity within the subject. In some applications, detection and identification are important while in others precise measurement of radioactivity is more crucial. Therefore, depending on the use, the three determinants are given different priorities. Although quantitative measurements can be made using energetic beta radiation also, however by and large, the investigations in the bio-medical field employing whole body counter are confined to low as well as high energy gamma photons.

3. Detectors

Large variety of inorganic and organic detectors are in use. Organic radiation detectors are normally less expensive and have poor energy resolution. By and large Thallium activated Sodium Iodide-NaI(Tl)crystal detectors optically coupled to photomultiplier, are the detectors of choice for most of the common applications. With this detector, the photoelectric effect is the dominant interaction for incident gamma radiation which is absorbed by the crystal material and the resulting energy spectrum have characteristic well defined photo peaks. Although detectors with better energy resolution are available, yet NaI(Tl) detectors still dominate the scene due to their good detection efficiency and reasonably decent energy resolution.

Liquid scintillator and plastic scintillator materials are less expensive and easier to handle. Because of low atomic number of the elements present in the material, the incident gamma radiation interacts with the scintillator mainly by compton scattering and therefore the spectral resolution – unlike that due to NaI(Tl) detectors, is poor. Due to lower cost than NaI(Tl) crystals, large size detectors covering more or less the entire human body are being made with these scintillators.

Besides these detectors there are some that are used for special purposes. Thin window proportional counter and low background high sensitivity sodium iodide sandwich detectors find applications for low energy gamma and x-radiation.

4. Detector – Subject geometry

Essentially a whole body counter detects a fraction of gamma radiation emitted from the radionuclides in the human body. From the observed counting rate and suitable calibration procedure, the amount of radioactivity within the subject can be estimated. Ideally counter efficiency should be independent of the distribution of activity in the subject. For this reason multi-detector NaI(Tl) crystal detector system or large volume organic scintillators are used in preference to single NaI(Tl) detector. Initially International Atomic Energy Agency identified a number of Detector - Subject geometries, however, at present large volume pastic scintillator or NaI(Tl) crystal multi detector system in a shielded room or NaI(Tl) crystal detectors system in a scanning mode, are most favoured ones.

5. Shielding

Because of the levels of radioactivity to be measured are very low, the high sensitivity detectors must be shielded from the radiation from cosmic and terrestrial radiation or from residual radioactivity in the immediate environment. A completely shielded room either with iron or lead with filtered air supply may be ideal. Chalk or other compounds that are low in inherent radioactivity, have also been used as shielding materials. A less expensive alternative which is adequate for most of the clinical studies and medical research in the shadow shield system in which the detectors only are shielded locally with lead. The system is carefully designed so that no background radiation reaches the detectors without passing through the shielding. Great care is to be taken in selecting the constructing material as well as other provision and fixtures of the whole body counter.

6. Applications

Applications of whole body counter in the field of radiation protection are well documented. In the present communication, its use in the field of clinical diagnosis and medical research will be highlighted. The popularity of the methodology in the field stems largely from the relative ease of measurement, accuracy of results, minimum radiation dose to the patient, the possibilities of conducting long term studies even in radio-sensitive groups and carrying out most of the investigations on an out patient basis. However, the clinical usefulness of the methodology is to be evaluated in four respects : (a) its unique capabilities, (b) in comparison with clinical tests intended to provide analogous information, (c) patient amenity and comfort and (d) economic factors. It is well accepted that whole body counter have economic advantages as well as superiority in accuracy, reliability and convenience.

A classical medical application of the whole body monitoring techniques makes use of a naturally occurring radioactive isotopes of potassium. Potassium contains 0.0118% gamma emitting ^{40}K. By quantitating the ^{40}K activity in a subject and comparing with humanoid phantom studies, the body content of naturally occurring potassium can be obtained. Since 98% of body potassium is intracellular with only low concentration in fat, it can be directly correlated to the protein rich lean body mass. The measurement of total body potassium can therefore be useful to estimate lean tissue degradation (catabolism) or its synthesis (anabolism).

The most important use of whole body monitors in medical research is in the study of dynamic metabolic processes which characterise all living organisms. The term dynamic studies is commonly associated with those processes where the tracer has the mean transit time measured in seconds or minutes. There are many equally important processes with transit times measured in days or months or even years. Their study necessitates the use of long lived radioactive tracer

and low administered dose levels. The high sensitivity whole body counter is an ideal and essential tool for such type of studies.

The gastrointestinal absorption of essential dietry components can be easily measured by incorporating radioactive labels in the components of interest. Whole body activity due to the labelled component is measured in a whole body monitor just after its oral administration. After a week or so by which time the unabsorbed fraction of the component has been fecally excreted, the activity in the subject is remeasured and compared with the initial value. Iron absorption have been studied extensively from a large number of foods and in various clinical conditions. Absorption of Vitamin B_{12} in normals and in patients with pernicious anaemia, is another field where whole body counting has been employed fruitfully.

Whole body monitor can be used to measure the body content of normally stable elements. The whole body is irradiated with a uniform flux of neutrons which interact with atoms in the body inducing radioactivity. The induced radioactivity resulting from neutron activation of a particular element is proportional to the amount of that element in the body and it can be quantitated by comparing the activity of the irradiated subject to that of an irradiated humanoid phanton containing a known amount of the element.

7. Work carried out at INMAS

At the Institute of Nuclear Medicine and Allied Sciences, Delhi - one of the leading laboratories of Defence Research and Development Organisation, an advanced whole body counter is functional since 1972. The objective was to choose a particular design, detector system and geometry, shielding and electronics so that a single versatile system could meet all the requirements of radiation protection as well as those of clinical applications that were in mind at that time. A number of physical studies were carried out to meet the requirements of the two proposed applications that often were opposed to each other.

Efforts were directed to have physiological norms for Indian population and body potassium measurements were carried out in about 400 subjects. Further total body potassium levels were correlated with sex, age, weight, height and food habits. Total body potassium measurements were also carried out in patients with thyrotoxicosis, iron deficiency, Vitamin B_{12} deficiency, myopathy and nephrotic syndrome. In this limited study, except in cases with myopathy where a moderate despression in total body potassium was observed, no significant changes could be detected in other clinical conditions.

Iron absorption studies were carried out in normal as well as in patients with iron deficiency anaemia and thyrotoxicosis. The methodology was also applied to estimate iron stores and the restults were correlated with the ones obtained by DFO excretion method. Due to many inherent advantages of this methodology over the conventional tests, excellent results were obtained.

Vitamin B_{12} absorption investigations were also carried out in normals and in subjects with malabsorption syndrome. It was demonstrated that haematinic supplementation increases absorption of Vitamin B_{12} also.

8. Conclusion

Besides these clinical studies a whole body counter of the type that is at INMAS may be of great value in many other situations. Management of disasters involving radioactivity is one of the foremost use in the present context.